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MATHEMATISCHE CENTRUM

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IW 23/75 CALL-BY-VALUE VERSUS CALL-BY-NAME: A PROOF-THEORETIC COMPARISON
W. P. de Roever

Minimal fixed point operators were introduced by SCOTT and DE BAKKER in order to describe the input-output behaviour of recursive procedures. As they considered recursive procedures acting upon a monolithic state only, i.e., procedures acting upon one variable, the problem remained open how to describe this input-output behaviour in the presence of an arbitrary number of components which as a parameter may be either called-by-value or called-by-name. More precisely, do we need different formalisms in order to describe the input-output behaviour of these procedures for different parameter mechanisms, or do we need different minimal fixed point operators within the same formalism, or do different parameter mechanisms give rise to different transformations, each subject to the same minimal fixed point operator?

Using basepoint preserving relations over cartesian products of sets with unique basepoints, we provide a single formalism in which the different combinations of call-by-value and call-by-name are represented by different products of relations, and in which only one minimal fixed point operator is needed. Moreover this mathematical description is axiomatized, thus yielding a relational calculus for recursive procedures with a variety of possible parameter mechanisms.

IW 39/75 HOW PROGRAM STATEMENTS TRANSFORM PREDICATES
L. Ammeraal

This paper deals with relationships between conditions that hold before the initiation of a statement and on its completion. Statements are semantically defined by statement functions which are transformations in the state space. They induce predicate transformers which map state space subsets to such subsets. The predicate transformers and their inverses are explicitly given for some well-known constructs including the conditional statement and the while statement. A number of examples illustrate how predicate transformers can be used.

IW 49/75 CONTEXT SENSITIVE TABLE LINDENMAYER LANGUAGES AND A RELATION TO THE LBA PROBLEM
P. M. B. Vitanyi

Families of languages generated by classes of context sensitive Lindenmayer systems with tables using nonterminals are classified in the Chomsky hierarchy. It is shown that the family of languages generated by deterministic λ-free left context sensitive L systems with two tables using nonterminals coincides with the context sensitive languages. Combined with the fact that the family of languages generated by deterministic λ-free context sensitive L systems (with one table) using nonterminals is equal to the DLBA languages this shows the classic LBA problem to be equivalent to whether or not a trade-off is possible between one sided context with two tables and two sided context with one table for deterministic λ-free L systems using nonterminals.

Without the restriction to λ-freeness such a trade-off is possible since the recursively enumerable languages are generated in both cases. By stating the results in their strongest form a complete classification of the considered language families is obtained since the hierarchies induced by the involved parameters (λ-freeness, determinism, number of tables, amount of context, closure under various types of homomorphisms) basically collapse to the recursively enumerable languages, context sensitive languages and DLBA languages.

IW 52/75 REPAIRING THE PARENTHESIS SKELETON OF ALGOL 68 PROGRAMS: PROOFS OF CORRECTNESS
L. G. L. T. Meertens and J. C. van Vliet

The error-correction problem for structures of nested parentheses bears some resemblance to the problem of finding the shortest path in a direected graph. Not surprisingly, the algorithm for determining the optimal "reparation" lends itself to a neat and concise (min, +)-algebraic notation, thus permitting abstraction from the respresentation used in a practical implementation. The correctness proof for this abstract algorithm may then be given with only a few inductive assertions.

IW 55/76 CORRECTNESS PROOFS FOR ASSIGNMENT STATEMENTS
J. W. de Bakker

Correctness proofs for assignment statements are usually based on Hoare's or Floyd's assignment axiom. We observe that these axioms do not apply (directly) to assignment for subscripted variables. A refined definition of substitution for subscripted variables, which preserves the validity of Hoare's axiom, and which is used in the formulation of an extension of Floyd's axiom, is proposed. For both axioms, a validity proof is given within the framework of denotational semantics of Scott and Strachey. Moreover, it is shown that they yield the weakest precondition and strongest postcondition, respectively.

STATE UNIVERSITY OF NEW YORK AT ALBANY

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#75-1 ON UNSOLVABILITY IN SUBRECURSIVE CLASSES OF PREDICATES
F. D. Lewis

#75-2 ON ONE FAMILY OF BOOLEAN FUNCTIONS
Y. Breitbart

#76-1 SUBRECURSIVE REDUCIBILITIES AND COMPLETENESS (PRELIMINARY VERSION)
F. D. Lewis

#76-2 HOW NOT TO ESTABLISH COMPLEXITY BOIUNDS FOR THE CONTEXT FREE LANGUAGES
F. D. Lewis

#76-3 COMPLEXITY OF MINIMAL SUM OF PRODUCTS FOR ONE BOOLEAN FUNCTION
Y. Breitbart

INTERNATIONAL BUSINESS MACHINES

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RC 6108 ON THE NUMBER OF PRIME IMPLICANTS
Ashok K. Chandra and George Markowsky

ABSTRACT: It is shown that any Boolean expression in disjunctive normal form having k conjuncts, can have at most 2^k prime implicants. However, there exist such expressions that have $2^{k/2}$ prime implicants. It is also shown that any Boolean expression on n distinct propositional variables can have at most $O\left(\frac{3^n}{\sqrt{n}}\right)$ prime implicants, and there exist expressions with $O\left(\frac{3^n}{n}\right)$ prime implicants.

RC 6116 RATIONAL ALGEBRAIC THEORIES AND FIXED-POINT SOLUTIONS
J. B. Wright, J. A. Goguen, J. W. Thatcher & E. G. Wagner

ABSTRACT: In a wide variety of situations, computer science has found it convenient to define complex objects as (fixed-point) solutions of certain equations. This has been done in both algebraic and order-theoretic settings, and has often been contrasted with other approaches. This paper shows how to formulate such solutions in a setting which encompasses both algebraic and order-theoretic aspects, so that the advantages of both worlds are available. Moreover, we try to show how this is consistent with other approaches to defining complex objects, through a number of applications, including: languages defined by context-free grammars; flow charts and their interpretations; and monadic recursive program schemes. The main mathematical results concern free rational theories and quotients of rational theories. However, the main goal has been to open up what we believe to be a beautiful and powerful new approach to the syntax and semantics of complex recursive specifications.

RC 6151 A NEW LINEAR-TIME ON-LINE RECOGNITION ALGORITHM FOR "PALSTAR"
Zvi Galil & Joel Seiferas

ABSTRACT: Let $P_1=\{w \in \Sigma^*: w = w^R, |w|> 1\}$ be the set of all nontrivial palindromes over Σ. A linear-time on-line recognition algorithm is presented for P_1^* ("palstar") on a random-access machine with addition and uniform cost criterion. Also presented are a linear-time on-line recognition algorithm for P_1^2 on a multitape Turing machine and a recognition algorithm for P_1^2 on a two-way deterministic pushdown automaton. The correctness of these algorithms is based on a new "cancellation lemmas" for the languages P_1^* and P_1^2.

RC 6154 A COMPUTATIONAL ALGORITHM FOR QUEUE DISTRIBUTIONS VIA PÓLYA THEORY OF ENUMERATION
Hisashi Kobayashi

ABSTRACT: We present a new computational algorithm for evaluating the queue distribution in a general Markovian queuing network, based on Pólya theory of counting. We formulate queue size vectors as counting schemata - equivalence classes - relative to a symmetric group. The normalization constant of the queue-distribution then corresponds to the pattern inventory - the sum of weights of schemata relative to the permutation group - in the Pólya theory.

RC 6164 PROBABILISTIC ALGORITHMS
Michael O. Rabin

ABSTRACT: We study the implications of randomization within an algorithm on the computational complexity of certain problems. One version of this approach produces a substantial reduction in expected computation time for every instance of the problem of finding the nearest pair in a set of n points. Another version, which allows a controllable small margin of error, yields an extremely fast test for primality of any given large number.

RC 6193 MAXIMAL PARALLELISM IN MATRIX MULTIPLICATION
Ashok K. Chandra

ABSTRACT: It is shown that Strassen's matrix multiplication algorithm which runs in time $O(n^{\log 7})$ on one processor, can be made to run in time $O(n^{\log 7}/p)$ on p processors, for $p \leq n^{\log 7}/\log n$. The upper bound on the maximum number of processors that can be used effectively, viz. $O(n^{\log 7}/\log n)$ is, of course, tight since matrix multiplication requires time at least $O(\log n)$. The matrix multiplication algorithm can be used for other problems including transitive closure and context free recognition.

RC 6214 SPECIFICATION OF ABSTRACT DATA TYPES USING CONDITIONAL AXIOMS
J. W. Thatcher, E. G. Wagner & J. B. Wright

RC 6230 ON THE ALGEBRAIC STRUCTURE OF ROOTED TREES
Calvin C. Elgot, Stephen L. Bloom & Ralph Tindell

ABSTRACT: Many kinds of physical phenomena are studied with the aid of (rooted) diagraphs such as those indicated by Figure 1.1 and Figure 1.2.

Figure 1.1

Figure 1.2

These two diagraphs, while different, usually represent the same phenomenon say, the same "computational process." Our interest in rooted trees stems from the fact that these two diagraphs "unfold" into the SAME infinite tree. In some cases at least it is also true that different (i.e. non-isomorphic) trees represent different phenomena (of the same kind). In these cases the unfoldings (i.e. the trees) are surrogates for the phenomena.

HERIOT-WATT UNIVERSITY

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#3 AN IMPROVED ITERATIVE ALGORITHM FOR GLOBAL DATA FLOW ANALYSIS
R. C. Backhouse

Kam and Ullman have presented two algorithms for solving general data flow analysis and code optimisation problems and have discussed conditions under which their algorithms are efficient. In this paper we present an algorithm which always terminates in the same number or fewer iterations than both the algorithms of Kam and Ullman. Moreover, the number of function applications required by the algorithm is always less than the number of function applications required by both the algorithms of Kam and Ullman. The improvement is gained by making a simple modification to the order in which edges are accessed during each iteration of the Kam and Ullman algorithms.

It should be stressed that this is not a worst-case or average-case analysis but is quite independent of the input.

#4 FACTOR GRAPHS, FAILURE FUNCTIONS AND BI-TREES
R. C. Backhouse and R. K. Lutz

The factors and factor matrix of a regular language are defined and their properties stated. It is then shown that the factor matrix of a language Q has a unique starth root - called the factor graph of Q - which is a recogniser of Q. An algorithm to calculate the factor graph is presented. The Knuth, Morris and Pratt pattern matching algorithm, its extensions and Weiner's substring identifier algorithm are outlined and are all shown to be equivalent to finding the factor graph of some regular language.

CARNEGIE-MELLON UNIVERSITY

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THE MEAN DISTANCE IN 2-SPACE
G. Yuval

An $O(N^2)$ lower bound is proven for the mean distance between N points in 2-space, using methods from complex function theory; but if any finite error is allowed, an O(NlogN) algorithm is shown for computing the mean distance to within that finite error.

ALL ALGEBRAIC FUNCTIONS CAN BE COMPUTED FAST
H. T. Kung and J. F. Traub

The expansions of algebraic functions can be computed "fast" using the Newton Polygon Process and any "normal" iteration. Let M(j) be the number of operations sufficient to multiply to jth degree polynomials. It is shown that the first N terms of an expansion of any algebraic function defined by an nth degree polynomial can be computed in O(n(M(N)) operations, while the classical method needs $O(N^n)$ operations. Among the numerous applications of algebraic functions are symbolic mathematics and combinatorial analysis. Reversion, reciprocation, and nth root of a polynomial are all special cases of algebraic functions.

ANALYSIS OF THE BINARY EUCLIDEAN ALGORITHM
Richard P. Brent

The binary Euclidean algorithm of Silver and Terzian and Stein finds the greatest common divisor (GCD) of two integers, using the arithmetic operations of substraction and right shifting (i.e., division by 2). Unlike the classical Euclidean algorithm, no divisions are required. Thus, an iteration of the binary algorithm is faster than an iteration of the classical algorithm on many binary computers.

TOKYO INSTITUTE OF TECHNOLOGY

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C-1 A NOTE ON EXTENDING EQUIVALENCE THEORIES OF ALGORITHMS

Kojiro Kobayashi

By an equivalence theory of algorithms we mean an axiomatic theory in which functional equivalences of programs expressed in a programming language are proved. Under the assumption that all partial recursive functions are expressible in the programming language, we show that from any equivalence theory of algorithms E we can effectively construct an extended equivalence theory of algorithms E' such that for any program P there exists another program P' whose functional equivalence with P is proved in E' but not in E.

C-2 GENERALIZATION OF REGULAR SETS AND THEIR APPLICATION TO A STUDY OF CONTEXT-FREE LANGUAGES

Masako Takahashi

We extend the notion of regular sets of strings to those of trees and of forests in a unified mathematical approach, and investigate their properties. Then by taking certain one-dimensional expressions of these objects, we come to an interesting subclass of CF languages defined over paired alphabets. They are shown to form a Boolean algebra with the Dyck set as the universe, and to play an important role in the whole class of CF languages. In particular, using the subclass we prove a refinement of the well-known Chomsky-Schutzenberger Theorem, and also prove that the decision procedure for parenthesis grammars can be extended to a broader class of CF grammars.

C-3 THE FIRING SQUAD SYNCHRONIZATION PROBLEM FOR ARBITRARY TWO-DIMENSIONAL ARRAYS

Kojiro Kobayashi

We consider the firing squad synchronization problem for arbitrary two-dimensional arrays and arbitrary positions of the general. We construct (1) a solution having firing time 2N (N is the number of the cells in the given array), (2) solutions having minimal firing time for arrays in some classes of arrays and (3) (for each K) a solution having a "linear" firing time for any array having not more than K edges. We also show examples of string-type arrays, i.e. lines of breadth 1 without loops (the position of the general is one of the ends), of length N whose minimal firing time is less than 2N - 2.

C-4 GENERALIZED PARENTHESIS GRAMMARS AND A DESCRIPTION OF ALGOL
Masako Takahashi

The generalized parenthesis grammars are certain type of context-free grammars including the parenthesis grammars, the bracketed context-free grammars, the right-linear grammars, as well as the one to generate a set of ordinary arithmetic expressions. We will study the properties of the grammars by relating them to tree automata. In particular, applying the result known in tree automata theory, we give a direct proof of the fact that the equivalence problem for the grammars is solvable. At last, we will give a detailed (but compact) description of a substantial part of ALGOL, to exhibit the generating power of the grammars.

C-5 MINIMUM FIRING TIME OF THE TWO-DIMENSIONAL FIRING SQUAD SYNCHRONIZATION PROBLEM
Kojiro Kobayashi

We consider the firing squad synchronization problem for arbitrary two-dimensional arrays. For each array F, $t_{min}(F)$ denotes the minimum firing time of the array F where all the solutions to this problem are considered. We give one characterization of this value $t_{min}(F)$ in terms of geometric properties of the shape of the array F. From this we show an algorithm to calculate the value $t_{min}(F)$.

UNIVERSITY OF ALBERTA

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TR76-4 AN ALGORITHM FOR SOLVING SHORTEST ROUTES FROM A FIXED ORIGIN IN A DIRECTED GRAPH
I-Ngo Chen

TR76-5 A FAST METHOD FOR FINDING NEGATIVE CYCLES IN A DIRECTED GRAPH
I-Ngo Chen

UNIVERSITY OF KARLSRUHE

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#46 ON GOOD EOL FORMS
H. A. Maurer, A. Salomaa & D. Wood

This paper continues the study of EOL forms. The notion of a good EOL form is introduced as an important generalization of the notion of complete and very complete EOL forms. Transformations preserving the property good are obtained and the existence of a variety of good and bad (i.e. not good) forms is demonstrated. It is further shown that good and complete (i.e. vomplete) EOL forms do exist; that propagating EOL forms are bad except under very special circumstances; and that synchronized EOL forms are always bad.

#47 TREE CONTROLLED GRAMMARS
K. Culik II & H. A. Maurer

Languages are studied which can be generated by context-free grammars under a single simple restriction which must be satisfied by its derivation trees. Using tree controlled grammars (TC grammars for short) all unambigous and some inherently ambigous context-free languages, and also some non context-free languages can be parsed in time $O(n^2)$. The classes of regular, linear, context-free, EOL, ETOL and type 0 languages is exhibited. Some normal forms for TC grammars are established but it is shown that many common normal forms (e.g. Greibach normal form) cannot be obtained for TC grammars in general.

-- ETOL FORMS
H. A. Maurer, A. Salomaa & D. Wood

This paper explores the notions of "tabled L form" and its "interpretations", which produce a family of structurally similar ETOL systems. Biologically this is the study of a family of organisms which are similar developmentally. In particular, the tables ensure a similarity of changing environmental conditions under which each organism develops.
We demonstrate a number of normal form results for ETOL forms, which carry over in a nontrivial way from ETOL systems. The main section of the paper investigates "completeness", this leads to the surprising discovery of a normal form in which the only rules for terminals are $a \to a$.

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76-16 CONSTRAINTS ON STRUCTURAL DESCRIPTIONS: LOCAL TRANSFORMATIONS
Aravind K. Joshi & Leon S. Levy

ABSTRACT: It is very often more convenient and more meaningful to specify a set of structural descriptions analytically rather than generatively, i.e., by specifying a set of constraints each structured description in the set has to satisfy. Peters and Ritchie (5) have show that if context-sensitive rules are used only for "analysis" then the string language of the set of trees is still context-free In this paper, we have generalized this result by considering context-free rules constrained by boolean combinations of proper analysis predicates and domination predicates. These rules, called "local transformations" not only make precise an informal and briefly discussed notion of Chomsky (?), but also, generalize it in an appropriate manner. It is shown that the Peters-Ritchie result can be generalized to local transformations. Linguistic relevance of this result has been also briefly discussed. Results in this paper are relevant to the following situation: Patterns of a class, say A, may be difficult to characterize generatively; but, it may be possible to specify a suitable (non-trivial) augmentation, say B, of the class A, such that B can be easily characterized generatively, and then A is characterized by stating some restrictions on the class B. This suggests possible applications to programming languages and pattern description languages.